

**Phosphor for light sources and associated light source****Cross References to Related Applications**

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This application is a continuation of copending application Serial No. 09/787,208, filed 3/15/2001.

**Technical field**

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The invention relates in particular to a yellow-emitting garnet phosphor for excitation by a light source with short wavelengths in the visible blue spectral region, with the result that white light is generated. A lamp (primarily a fluorescent lamp) or an LED (light-emitting diode) is particularly suitable as the light source.

**Prior art**

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WO 98/05078 has already disclosed a phosphor for light sources and an associated light source. In that document, the phosphor used is a garnet of the structure  $A_3B_5O_{12}$ , the host lattice of which, as first component A, comprises at least one of the rare earths Y, Lu, Sc, La, Gd or Sm. Furthermore, one of the elements Al, Ga or In is used for the second component B. The only dopant used is Ce.

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A very similar phosphor is known from WO 97/50132. The dopant used in that document is either Ce or Tb. While Ce emits in the yellow spectral region, the emission from Tb is in the green spectral region. In both cases, the complementary color principle (blue-emitting light source and yellow-emitting phosphor) is used to achieve a white luminous color.

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Finally, EP-A 124 175 describes a fluorescent lamp which, in addition to a mercury fill, contains a plurality of phosphors. These are excited by UV radiation (254 nm) or also by short-wave radiation at 5 460 nm. Three phosphors are selected in such a way that they add up to form white (color mixture).

### Summary of the invention

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According to the invention, for light sources from which the emission lies in the short-wave optical spectral region, a phosphor which has a garnet 15 structure  $A_3B_5O_{12}$  and which is doped with Ce is used, the second component B representing at least one of the elements Al and Ga and the first component A containing terbium. Surprisingly, it has been found that under particular circumstances, namely under blue excitation 20 in the range from 420 to 490 nm, terbium (Tb) is suitable as a constituent of the host lattice (first component of the garnet) for a yellow-emitting phosphor, the activator of which is cerium. Previously, in this context Tb has only been considered as an 25 activator or coactivator, together with cerium, for emission in the green region, if excitation is produced by cathode rays (electrons) or short-wave UV photons (GB-A 1 600 492 and EP-A 208 713).

30 In this case, terbium, as the principal constituent of the first component A of the garnet, can be used on its own or together with at least one of the rare earths Y, Gd, La and/or Lu.

35 At least one of the elements Al or Ga is used as the second component. The second component B may additionally contain In. The activator is cerium. In a

particularly preferred embodiment, a garnet of the structure

$(\text{Tb}_{1-x-y}\text{RE}_x\text{Ce}_y)_3(\text{Al},\text{Ga})_5\text{O}_{12}$ , where

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RE = Y, Gd, La and/or Lu;

$0 \leq x \leq 0.5 - y$ ;

10  $0 < y < 0.1$  is used.

The phosphor absorbs in the range from 420 to 490 nm and can thus be excited by the radiation from a blue light source, which is in particular the radiation  
15 source for a lamp or LED. Good results have been achieved with a blue LED whose emission peak was at 430 to 470 nm. The emission peak of the Tb-garnet: Ce phosphor is at approximately 550 nm.

20 This phosphor is particularly useful for use in a white LED based on the combination of a blue LED with the Tb-garnet-containing phosphor, which is excited by absorption of part of the emission from the blue LED and the emission from which supplements a remaining  
25 radiation from the LED, to form white light.

A Ga(In)N-LED is particularly suitable as the blue LED, but any other route for producing a blue LED which emits in the range from 420 to 490 nm is also suitable.  
30 430 to 470 nm is particularly recommended as the principal emission region, since this is where efficiency is highest.

By selecting the type and quantity of rare earths, it  
35 is possible to fine-tune the location of the absorption and emission bands, in a similar way to that which is known from the literature for other phosphors of type

YAG:Ce. In conjunction with light-emitting diodes, it is particularly suitable for x to be  $0.25 \leq x \leq 0.5 - y$ .

The particularly preferred range for y is  $0.02 < y < 0.06$ .

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The phosphor according to the invention is also suitable for combination with other phosphors.

A garnet of structure

10  $(Tb_x RE_{1-x-y} Ce_y)_3 (Al, Ga)_5 O_{12}$ ,

where RE = Y, Gd, La and/or Lu;

$0 \leq x \leq 0.02$ , in particular  $x = 0.01$ ;

0 < y < 0.1 has proven particularly suitable as the  
15 phosphor. Y frequently lies in the range from 0.01 to 0.05.

Generally, relatively small amounts of Tb in the host lattice serve primarily to improve the properties of  
20 known cerium-activated phosphors, while the addition of relatively large amounts of Tb can be used in a controlled way in particular to shift the wavelength of the emission from known cerium-activated phosphors. Therefore, a high proportion of Tb is particularly  
25 suitable for white LEDs with a low color temperature of below 5000 K.

#### **Brief description of the drawings**

30 The invention is to be explained in more detail below with reference to a number of exemplary embodiments. In the drawing:

Figure 1 shows an emission spectrum of a first Tb-garnet phosphor;  
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Figure 2 shows the reflectance spectrum of this Tb-garnet phosphor;

Figure 3 shows emission spectra of further Tb-garnet phosphors;  
Figure 4 shows reflectance spectra of the Tb-garnet phosphors from Figure 3;  
5 Figure 5 shows emission spectra for further Tb-garnet phosphors;  
Figure 6 shows reflectance spectra for the Tb-garnet phosphors from Figure 5;  
Figure 7 shows an emission spectrum for a white LED  
10 with Tb-garnet phosphor.

### **Detailed description of the invention**

#### Exemplary Embodiment No. 1:

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The components

	9.82 g	Yttrium oxide $Y_2O_3$
	2.07 g	Cerium oxide $CeO_2$
20	37.57 g	Terbium oxide $Tb_4O_7$
	26.41 g	Aluminum oxide $Al_2O_3$
	0.15 g	Barium fluoride $BaF_2$
	0.077 g	Boric acid $H_3BO_3$

25 are mixed and comminuted together for two hours in a 250 ml polyethylene wide-necked bottle using 150 g of aluminum oxide balls with a diameter of 10 mm. Barium fluoride and boric acid serve as fluxes. The mixture is fired for three hours in a covered corundum crucible at  
30  $1550^{\circ}C$  in forming gas (nitrogen containing 2.3% by volume hydrogen) and then milled in an automatic mortar mill and screened through a screen with a mesh width of  $53\ \mu m$ . This is followed by a second firing for three hours at  $1500^{\circ}C$  under forming gas (nitrogen containing  
35 0.5% by volume hydrogen). Then, milling and screening is carried out as after the first firing. The phosphor obtained corresponds to the composition  $(Y_{0.29}Tb_{0.67}Ce_{0.04})_3Al_5O_{12}$ . It has a strong yellow body

color. An emission spectrum for this phosphor when excited at 430 nm and a reflectance spectrum for the phosphor between 300 and 800 nm are shown in Figures 1 and 2.

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Exemplary Embodiment No. 2:

The components

10	43.07 g	Terbium oxide $Tb_4O_7$
	1.65 g	Cerium oxide $CeO_2$
	21.13 g	Aluminum oxide $Al_2O_3$
	0.12 g	Barium fluoride $BaF_2$
	0.062 g	Boric acid $H_3BO_3$

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are intimately mixed and processed as described under Example 1. The phosphor obtained corresponds to the overall composition  $(Tb_{0.96}Ce_{0.04})_3Al_5O_{12}$  or, in the representation which illustrates the host lattice,  $Tb_3Al_5O_{12}:Ce$ . It has a strong yellow body color. The X-ray diffraction diagram shows that there is a cubic garnet phase. The emission spectrum and reflectance spectrum for this phosphor are shown in Figures 3 and 4, respectively.

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Exemplary Embodiment No. 3:

The components

30	32.18 g	Yttrium oxide $Y_2O_3$
	0.56 g	Terbium oxide $Tb_4O_7$
	2.07 g	Cerium oxide $CeO_2$
	26.41 g	Aluminum oxide $Al_2O_3$
	0.077 g	Boric acid $H_3BO_3$

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are intimately mixed and processed as described under Example No. 1. The phosphor obtained corresponds to the composition  $(Y_{0.95}Tb_{0.01}Ce_{0.04})_3Al_5O_{12}$ . It has a strong

yellow body color. The emission spectrum and reflectance spectrum for this phosphor are shown in Figures 3 and 4, respectively.

5 Exemplary Embodiment No. 4:

The components

	26.76 g	Yttrium oxide $Y_2O_3$
10	9.53 g	Terbium oxide $Tb_4O_7$
	2.07 g	Cerium oxide $CeO_2$
	26.41 g	Aluminum oxide $Al_2O_3$
	0.149 g	Barium fluoride $BaF_2$
	0.077 g	Boric acid $H_3BO_3$

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are intimately mixed and processed as described under Example No. 1. The phosphor obtained corresponds to the composition  $(Y_{0.79}Tb_{0.17}Ce_{0.04})_3Al_5O_{12}$ . It has a strong yellow body color. The emission spectrum and reflectance spectrum for this phosphor are shown in Figures 3 and 4, respectively.

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Exemplary Embodiment No. 5

25 The components

	30.82 g	Yttrium oxide $Y_2O_3$
	0.56 g	Terbium oxide $Tb_4O_7$
	4.13 g	Cerium oxide $CeO_2$
30	26.41 g	Aluminum oxide $Al_2O_3$
	0.149 g	Barium fluoride $BaF_2$
	0.077 g	Boric acid $H_3BO_3$

are intimately mixed and processed as described under Example No. 1. The phosphor obtained corresponds to the composition  $(Y_{0.91}Tb_{0.01}Ce_{0.08})_3Al_5O_{12}$ . It has a strong yellow body color.

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Exemplary Embodiment No. 6:

The components

5	43.07 g	Terbium oxide $Tb_4O_7$
	1.65 g	Cerium oxide $CeO_2$
	21.13 g	Aluminum oxide $Al_2O_3$
	0.062 g	Boric acid $H_3BO_3$

- 10 are intimately mixed and processed as described under Example 1, except that the temperature during the two firings is lower by 50°C in each case. The phosphor obtained corresponds to the composition  $(Tb_{0.96}Ce_{0.04})_3Al_5O_{12}$ . It has a strong yellow body color.
- 15 The emission spectrum and reflectance spectrum for this phosphor are shown in Figures 5 and 6, respectively.

Exemplary Embodiment No. 7:

20 The components

	43.07 g	Terbium oxide $Tb_4O_7$
	1.65 g	Cerium oxide $CeO_2$
	17.05 g	Aluminum oxide $Al_2O_3$
25	7.50 g	Gallium oxide $Ga_2O_3$
	0.062 g	Boric acid $H_3BO_3$

- are intimately mixed and processed as described under Example 1, except that the temperature for the two firings is lower by 50°C in each case. The phosphor obtained corresponds to the composition  $(Tb_{0.96}Ce_{0.04})Al_4GaO_{12}$ . It has a strong yellow body color. The emission spectrum and reflectance spectrum for this phosphor are shown in Figures 5 and 6, respectively.

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Exemplary Embodiment No. 8:

The components



	43.07 g	Terbium oxide $Tb_4O_7$
	1.65 g	Cerium oxide $CeO_2$
	12.97 g	Aluminum oxide $Al_2O_3$
5	15.00 g	Gallium oxide $Ga_2O_3$
	0.062 g	Boric acid $H_3BO_3$

are intimately mixed and processed as described under Example 1, except that the temperature for the two firings is lower by  $50^\circ C$  in each case. The phosphor obtained corresponds to the composition  $(Tb_{0.96}Ce_{0.04})_3Al_3Ga_2O_{12}$ . It has a yellow body color. The emission spectrum and reflectance spectrum of this phosphor are shown in Figures 5 and 6, respectively.

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Exemplary Embodiment No. 9

The components

20	4.88 kg	Yttrium oxide $Y_2O_3$
	7.05 kg	Gadolinium oxide $Gd_2O_3$
	161.6 g	Terbium oxide $Tb_4O_7$
	595 g	Cerium oxide $CeO_2$
	7.34 kg	Aluminum oxide $Al_2O_3$
25	5.50 g	Boric acid $H_3BO_3$

are mixed for 24 hours in a 60 l polyethylene vessel. The mixture is introduced into crucibles made from aluminum oxide with a capacity of approx. 1 l and is fired in a pushed-bat kiln for 6 hours at  $1550^\circ C$  under forming gas. The fired material is milled in an automatic mortar mill and then finely screened. The phosphor obtained has the composition  $(Y_{0.50}Gd_{0.45}Tb_{0.01}Ce_{0.04})_3Al_5O_{12}$ . It has a strong yellow body color. The emission spectrum and reflectance spectrum for this phosphor are shown in Figures 3 and 4, respectively.

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Exemplary Embodiment 10 (LED):

When these phosphors are used in a white LED together with GaInN, a structure similar to that described in  
5 WO 97/50132 is employed. By way of example, identical fractions of phosphor in accordance with Example 1 and of phosphor in accordance with Example 4 are dispersed in epoxy resin and a LED with an emission peak of approximately 450 nm (blue) is encapsulated by this  
10 resin mixture. The emission spectrum of a white LED obtained in this way is shown in Figure 7. In this case, the mixture of the blue LED radiation with the yellow phosphor emission results in a color locus of  $x = 0.359/y = 0.350$ , corresponding to white light of  
15 color temperature 4500 K.

The phosphors described above generally have a yellow body color. They emit in the yellow spectral region. When Ga is added or used on its own instead of Al, the  
20 emission shifts more toward green, so that it is also possible in particular to achieve higher color temperatures. In particular, Ga-containing (or Ga,Al-containing) Tb-garnets and purely Al-containing Tb-garnets can be used in mixed form in order to be able  
25 to adapt to desired color loci.

**ABSTRACT**

**Phosphor for light sources, and associated light source**

5 A phosphor for light sources, the emission from which  
lies in the short-wave optical spectral region, as a  
garnet structure  $A_3B_5O_{12}$ . It is activated with Ce, the  
second component B representing at least one of the  
elements Al and Ga, and the first component A is  
10 terbium or terbium together with at least one of the  
elements Y, Gd, La and/or Lu.

In a preferred embodiment, a phosphor having a garnet  
of structure  $(Tb_{1-x-y}RE_xCe_y)_3(Al,Ga)_5O_{12}$ ,  
15 where  
RE = Y, Gd, La and/or Lu;  
 $0 \leq x \leq 0.5 - y$ ;  
 $0 < y < 0.1$  is used.

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